rate of rotation, while with the single hole the puff, though distinctly audible, remained the same monotonous sound, independent of sudden variations of the speed of the disk. The only change in character was that the intensity diminished with the lower rates of vibration.

From the foregoing, we have been led to the following conclusions:—

1. When sound is produced by a vibrating body, each individual wave of the series causing the tone stimulates the terminals of the auditory nerve. If the single vibrations are of such a nature as to be inaudible, no tone can be heard.

2. The individual vibrations can be heard when the rate of vibration is too slow for a distinctive tone to be appreciated.

3. The immediate succession of two waves, at rates of vibration above fifty per second, gives rise to a sensation of tone having the same pitch as that yielded by a prolonged series at the same rate.

That is to say, one can distinguish the tone produced when only two vibrations of a series reach the terminals of the auditory nerve.

4. Having worked for some time with rates of vibration near the limit of the lowest tones, we are forced to admit that we have not attained the skill (said to be attained by practice) of distinguishing small changes in pitch with rates of vibration below fifty per second; at least, in the case of pendular vibration, such as is produced by tuning forks or muscular contraction.

II. "On the Mechanism of the Closure of the Larynx. A Preliminary Communication." By T. P. ANDERSON STUART, M.D., Professor of Physiology, University of Sydney, N.S.W., Australia. Communicated by Professor E. A. SCHÄFER, F.R.S. Received December 10, 1891.

By a series of papers ending with that by myself with Dr. A. McCormick ('Journ. Anat. Physiol.,' January, 1892), it has been finally determined that the time-honoured doctrine of the closure of the larynx by a lid-like action of the epiglottis is quite untenable; but, so far as I am aware, no satisfactory account of how after all the larynx is closed voluntarily and reflexly has as yet been given. The determination of the positive side of the question was nevertheless the necessary sequel of the determination of the negative side; having settled how it *is not* closed, one naturally proceeded to enquire how the larynx *is* closed, since closed it at times must be, and that at its very entrance.

In the literature of the subject I find that there is considerable looseness of diction. "Closure of the larynx" may mean either "closure of the glottis," "closure of the vestibule," or "closure of

the superior aperture of the larynx." These are manifestly three very different things, and it is that of the superior aperture which was effected by the epiglottis according to the old doctrine. On account of this looseness of diction, the experiments of John Reid lose most of their value in this connexion.

Now when one reflects that closure of the glottis merely would still leave patent all that portion of the laryngeal cavity above the level of the glottis, the vestibule, a region exquisitely sensitive to mechanical irritation, one immediately perceives that if the epiglottis does not effect the closure, then some other agency must exist whereby the superior aperture of the larynx, its very entrance, is closed against the entrance of food particles during deglutition. It is quite immaterial where the closure takes place so far as closure of the larynx during forced efforts is concerned, but it is not immaterial where it is effected in deglutition, for the superior aperture, at least, must be closed, however much farther downwards the closure takes place. Were it to remain open, the vestibule of the larynx would be a regular funnel specially adapted, as it were, to take up particles of food. Such particles after the act of deglutition is over would need to be expelled by a violent expiration, a cough, or they would by their weight fall into, or by the force of the inspiratory air blast they would be drawn into, the lower passages. Now these things do not happen, so that *a priori* even, we may assume that the actual entrance to the larynx *is* closed, and experimentally I *have seen that it is* closed, while, on the other hand, Longet kept the margins of the glottis so apart that that aperture could not be closed, and yet the act of swallowing was carried out normally.

It may be well to give a straightforward account of how I have observed the larynx to be closed, and I shall then give details of experimental observations.

The observations were made on—

1. A man who had a large part of the side wall of the pharynx removed for carcinoma, without in any way interfering with the larynx. The man made a good recovery, and when feeding by the use of the stomach-tube was discontinued, he immediately swallowed as perfectly as he ever afterwards did, so that no education of the parts seemed necessary, and he continues to swallow about as well as he ever did, so that in function the parts are practically unimpaired. This man usually wears a rubber pad over the hole, but upon the removal of the same, that is, even with the hole open, one can watch with the unaided eye many of the phenomena of voluntary closure of the larynx, swallowing, coughing, singing, and so on. With the hole open a bolus of solid food is successfully swallowed, perhaps once out of three attempts; the other two times it will escape by the open hole.

2. A series of healthy persons examined laryngoscopically.

3. Frogs, Tortoises, Lizards, Birds, examined by simply opening the mouth and observing the top of the larynx, and the effects of stimulating certain of its muscles.

4. The Opossum, Cat, Dog, and Goat, anæsthetised with chloroform, and the laryngeal aperture examined through an incision in the middle line above the level of the epiglottis. Swallowing was observed as it occurred spontaneously or was evoked by irritating the pharyngeal mucous membrane. The relation of the tip of the epiglottis to the lower end of the incision formed an excellent guide as to whether or not the epiglottis moved. The complete closure of the larynx was tested by the stoppage of a current of air sucked down through the larynx.

In Man, and presumably in other animals with larynges of a like build, during respiration the arytenoid cartilages stand backwards and are rotated outwards. They, surmounted by the Santorinian cartilages and enveloped in the mucous membrane, are continually but somewhat irregularly advancing and retiring synchronously with the movements of expiration and inspiration. When they are backwards as in inspiration, the arytenoids, the posterior margin of the superior aperture of the larynx, lie against, and may indent, the posterior wall of the pharynx. In forced respiration these movements are exaggerated. The upward and backward direction continues more or less the direction of the plane of the lamina of the cricoid cartilage.

When the laryngeal entrance is to be closed, the arytenoid cartilages leave the posterior wall of the pharynx, are rotated and are moved bodily inwards, so as to bring their internal faces into contact, are inclined forwards, and glide forwards.

By the apposition of the arytenoids a mesial fissure makes its appearance, bounded posteriorly by the fold of mucosa containing the transverse arytenoid muscle and laterally by the arytenoids. The plane in which this fissure lies is, in Man in the erect posture, obliquely from before downwards and backwards. This fissure ends anteriorly in another fissure, which, however, is transverse; the two together constitute a triradiate fissure having the form of a squat T, the vertical limb being somewhat short, and the transverse limb rounded, owing to the pulling inwards, towards the middle line, of the margins of the epiglottis, so that the epiglottis thus forms a more marked hollow to receive the tips of the arytenoids.

The transverse fissure constituting the head of the T is bounded anteriorly by the epiglottis, and posteriorly by the ary-epiglottic folds. The ends of this fissure are closed by the junction of the ary-epiglottic folds with the margin of the epiglottis, and in the middle line posteriorly it receives the posterior or inter-arytenoid limb of the triradiate fissure.

Around the central point of this triradiate fissure are to be noted three prominences or thicknesses, viz., in front, and in the mesial plane, the cushion of the epiglottis more or less filling up the slight hollow left between the two prominences next to be mentioned, viz., slight thickenings at the point of flexion of the ary-epiglottic folds, where the lateral boundary of the antero-posterior limb of the fissure becomes continuous with the posterior boundary of the transverse portion; these are the tubercles of Wrisberg.

Having observed the appearances in the case of Dyason ('Jl. Anat. Physiol.,' *ut suprà*), I thought it advisable to get independent observations made by professed laryngologists, whom I had made acquainted with my observations. At my request, therefore, Dr. Barrett and Mr. Iredell, of Melbourne, kindly undertook to look into the matter, and here is what they say:—

Dr. Barrett.—"The appearances of the larynx as seen from above with the laryngoscope when closed during forcible expulsive efforts. A laryngoscopic examination was made in the cases of two young men with normal throats. They were directed to make expulsive efforts, as in defæcation. In both cases the appearances were similar. A view was first obtained during ordinary expiration, and then forcible expulsive efforts were made. The following changes occurred:—The cords and arytenoids approximated, and then the arytenoids moved forward until the mucous membrane and cornicula over them were firmly pressed against the epiglottis, at a point much higher than the attachment of the vocal cords. The epiglottis did not during the closure in any way alter its inclination, remaining vertical throughout. In one case, however, it became very much more curved round a vertical axis. It did not participate actively in the closure. The closed larynx may be said to show a triradiate figure like a shortened T, the vertical limb being much shortened, and representing the fissure between the arytenoids, and the crossed limb being somewhat curved."

Mr. Iredell.—"Undoubtedly during straining the posterior cartilages of the rim of the larynx come forward and appear to be about to form the figure you draw, but long before anything of the kind is perfect the muscular parts of the pharynx prevent all view. This is much more so during the act of swallowing. This much is clear: there is no sign of the epiglottis folding backwards and downwards, and as the act of swallowing proceeds this would appear to become more and more impossible. Yet there is an *appearance*—it may be only an appearance—of a tendency to move back the whole body of the tongue, carrying with it the epiglottis."*

* I believe that the difference in the amount seen by the two observers is due to the fact that Dr. Barrett probably used the cocaine spray, while Mr. Iredell did not. I remember that the former did use it in one case in my presence, while with the latter I did not speak of it.

If it be a simple voluntary closure of the laryngeal entrance, with or without expiratory effort, that is under observation, nothing further is to be noted. When the entrance is opened the arytenoids leave the epiglottis and then each other, are rotated outwards and backwards, move bodily outwards, glide backwards, and thus again assume the position they occupy in respiration.

If, however, the entrance is to be closed as a part of the act of swallowing, then, of course, the well known movement of the entire larynx upwards and forwards ensues, and the tips of the arytenoids are seen to be jammed firmly against the epiglottis. This is due partly to the thyro-arytenoid vigorously rotating the arytenoids inwards, and pulling them downwards and forwards, so that their tips come into contact with the base of the epiglottis; partly, however, it is due to the elevators of the larynx pulling the larynx upwards and forwards against the base of the tongue. In this position of the larynx the epiglottis lies between the rest of the larynx and the tongue and is firmly applied to both, is in fact compressed between them. It is, however, clear that if the epiglottis were not there the laryngeal entrance would still be closed, partly by the gathering up of its margins as above described, and partly by its direct contact with the base of the tongue, there being now no epiglottis to intervene.

The behaviour of the distal or apical portion of the epiglottis at this stage is not the same in all animals. In the Dog, for instance, the epiglottis is extremely flexible, and comparatively short, and is thus easily engaged between the tongue and the larynx. In the Dog, therefore, the distal portion of the epiglottis *has the appearance* of closing the laryngeal orifice in the lid-like way usually described as general in its application; but how little this is essential is at once evident when we remember the little or no inconvenience following its complete removal. In animals such as the Goat, which, like Man, has the distal portion of the epiglottis long and stiff, quite another picture is presented during this stage of the act of swallowing. It is only the base of the epiglottis which is engaged between the base of the tongue and the larynx; the distal portion does not fold down as a lid, but is applied to the most posterior part of the back of the tongue, so that the hollow laryngeal surface of the epiglottis continues backwards the surface over which the bolus glides from the tongue.

This, I think, may indicate the function of the hyo-epiglottic muscle about which there has been so much doubt. May it not serve to pull the epiglottis towards the hyoid bone during the act of deglutition, so that the epiglottis would be drawn upwards and forwards *with the larynx?* The hyo-epiglottic muscle would then stand in the same relation to the epiglottic cartilage as the hyo-thyroid muscle does to the thyroid cartilage. In this way the

epiglottis would lie on the tongue's surface, and be firmly pulled against it, so that the bolus would have less chance of getting between the epiglottis and the tongue in its passage downwards. Not all animals have this muscle, but then differences in the arrangements of the other parts may account for this. My experiments show that writers have hitherto taken too little notice of the differences in the anatomy of the larynx in different animals. These differences are very considerable.

I think we can generalise by saying that the closure of the larynx is invariably effected by contact of the arytenoids with each other and then contact of the two together with some part of the anterior wall of the laryngeal cavity, *but how this latter contact is effected* varies with the anatomical arrangements of the parts.

The extent of the contact of arytenoid with arytenoid varies. It may be (1) by the entire internal faces of the cartilages, (2) by an area along the anterior margin only, in which case the mucosa over it may be very thin and the whitish cartilage may show through, as in the Koala, or (3) the cartilages, though brought together, cannot, owing to their form, close the respiratory glottis (Milne Edwards).

We may, I think, divide* arytenoids into relatively large and relatively small. Then the former into relatively narrow and relatively broad. Thus we get three groups of arytenoid cartilages, viz., (1) high and narrow, (2) high and broad, (3) small.

In the high and narrow group the arytenoids fold over into contact with the front wall of the laryngeal cavity: the base of the epiglottis as I have described in Man and the Goat.

In the high and broad group, including many of the Marsupials I have examined, the arytenoids move more bodily forwards into contact with the base of the epiglottis, or at least the front of the vestibule.

In the group of small arytenoids, neither folding nor movement bodily forwards would suffice to effect the contact, and here the lower part of the epiglottis is permanently bent backwards, so that the wall of the upper and front part of the laryngeal cavity forms a little hood over the vocal cords, about the posterior margin of which hood the arytenoid contact takes place. In this case, therefore, the epiglottic base has, as it were (permanently), gone to meet the (small) arytenoids, which thus are able to effect the contact with a minimum of movement.†

In all cases I attach the greatest importance in effecting the laryngeal closure to the contact of the larynx as a whole with the

* Provisionally.

† On looking over the preparations of the larynx in the Hunterian Museum, I was struck with the frequency of this hooded condition of the epiglottis; it seems almost the rule.

base of the tongue, with or without the intervention of the epiglottic base. The movements of the arytenoids constitute a gathering up of the back and side boundaries, while its front boundary is virtually gathered up by its remaining stationary against the base of the tongue while the whole larynx moves forward. This is why swallowing is so often but little affected by the loss of the epiglottis by disease, accident, or experiment. Even loss of the arytenoids by disease does not seem to necessarily cause difficulties in deglutition.

I think it more than probable that there are differences between various species, and even between individuals of the same species, as to the importance of the part played by the tongue in closing the larynx. This seems to follow from the very various anatomical dispositions of the parts, and may account for much of the difference in the symptoms and signs of a particular laryngeal lesion in different individuals. In one case a lesion of the arytenoids or ary-epiglottic folds is not followed by difficulties of swallowing, while apparently the same, or even a less, degree of the same lesion in another case is followed by almost total inability to swallow, at all events, liquid food. For instance, in John Reid's experiments of cutting all the four laryngeal nerves in four Rabbits, two continued to take milk and two refused it. Two Dogs similarly treated continued to take both solids and liquids. In none of these cases was food found in the air passages after death. Reid therefore concludes that "the epiglottis . . . can prevent the ingress of food into the larynx when the movements of all the muscles which diminish the size of the glottis (*sic*) have been suspended by section of the laryngeal nerves." ("An Experimental Enquiry into the Function of the Eighth Pair of Nerves," 'Edinburgh Medical and Surgical Journal,' January, 1838.)

This same forward and upward movement of the larynx brings the lamina of the cricoid cartilage away from the back wall of the pharynx, and so provides the room necessary for the passage of the bolus. When the arytenoids are in position forwards, their highest points are their margins bounding the mesial fissure. This fissure thus traverses, as it were, a little ridge from before backwards, and from this ridge the top of the closed larynx slopes downwards at the sides and posteriorly, but especially at the sides.

Thus, when the laryngeal entrance is closed as for deglutition there is a fairly even surface for the bolus to glide over, from the laryngeal face of the epiglottis to the posterior surface of the arytenoids and lamina of the cricoid, and so into the gullet.

According to this account of the closure of the laryngeal entrance, the arytenoids enclosed in their mucosa—an arytenoid valve or flap—take the place of the epiglottis according to the old account, which is now all but universally discredited.

I have no doubt that the apparent fitness of the epiglottis as a lid

to cover the voice-box has given a longer life to the time-honoured doctrine of the functions of the epiglottis than it would otherwise have had; it seemed so beautifully fitted for its office that until recently it did not occur to any one to question it. Upon consideration, however, of the part played by the arytenoid valve according to my account, it appears to be much more beautiful than the part played by the epiglottis in the old account of the closure of the larynx, for, in addition to the merit of being demonstrably true, it co-ordinates and explains many observations hitherto without any connecting link or explanation, as will be set forth later on. In the meantime, however, I may point out how this arytenoid valve stands at the parting of the ways downwards out of the pharynx: when it stands backwards the food-passage is closed and the air-passage is open, when it lies forwards the air-passage is closed and the food-passage is open. Thus it can make, as it were, a funnel forwards into the air-tube or a funnel backwards into the food-tube. In short, and to use a particularly Australian illustration, it stands like the little movable gate by which sheep are drafted out of the common yard into separate pens—it drafts the air forwards and the food backwards.

This use of the term funnel is fully justifiable. In ordinary respiration, especially during inspiration, since the top of the arytenoid flap lies against—may even indent—the posterior pharyngeal wall, the way to the gullet is stopped, while the vestibule of the larynx is wide and patent, and, of course, is wide at the entrance and narrows downwards to the glottis. In this condition the shape of the entrance is apparently five-sided, though really there is a sixth, but comparatively small, side in the middle line posteriorly, where the transverse arytenoid muscle is. The anterior side is formed by the epiglottis. The lateral margins consist each of an anterior moiety formed by the ary-epiglottic fold, and of a posterior moiety containing the arytenoid tips and Santorinian cartilages. When the larynx of the Goat is exposed, this anterior funnel is peculiarly striking during forced inspiration, and the superior margin of it is almost circular, the violent outward and backward movement of the arytenoid tips pulling backwards the margin of the epiglottis, and so rounding off the anterior angles, and the flexible tips of the arytenoid and Santorinian cartilages yielding to the pull of the ary-epiglottic folds, and so rounding off the lateral angles.

The posterior funnel, though less striking, is hardly less real than the anterior one. It really exists only during the act of swallowing, and then also its anterior wall is composite and somewhat irregular. The anterior wall is formed above by the epiglottis, in the middle by the back of the arytenoid flap, and below by the back of the lamina of the cricoid. Now, while the epiglottis is always more or

less in position, the arytenoid portion is only there during closure of the laryngeal aperture, and the lamina of the cricoid is heaved forwards only during deglutition. Thus only during deglutition does the lamina of the cricoid form the inferior part of the anterior wall of a funnel.

Very much the same condition of parts is seen in *Manatus* (Waldeyer, 'Sitzungsb. der König. Preuss. Akad.,' Berlin, 1886). "Here one cannot speak of a bifurcation of the food channel as if it went to the right and left of the epiglottis, for, in *Manatus*, even small quantities of fluids must reach the œsophagus by passing straight over the larynx. Since, however, the laryngeal entrance is firmly closed in the way I have described, and so makes a surface gently inclined backwards, the entrance of liquids and solid foods is efficiently prevented."

The two funnels then, the air-funnel and the food-funnel, are alternately conditioned, the former solely, the latter largely, by the movement of the arytenoid flap backwards and forwards respectively.

In passing and in this connexion, one may point out a part played by the lamina of the cricoid. When the arytenoids move forwards their vocal processes move towards each other and at the same time downwards, so that the plane of the glottis comes to lie lower posteriorly. Anteriorly, of course, the plane is fixed by the attachment of the true cords to the thyroid cartilage. Thus the special vocal apparatus during deglutition lies deep down within the laryngeal cavity, and by the lamina of the cricoid is protected from the pressure of the bolus, pulled forwards, as it is, by the muscular slings of the inferior constrictor of the pharynx.

If we think of the old descriptions of the closure of the laryngeal entrance by the folding back of the epiglottis, we see at once that there would be a most awkward angle round which the bolus would have to travel just as it entered the gullet. This angle would be formed above by the tip of the epiglottis, and below by the posterior margin of the laryngeal entrance, *i.e.*, the tip of the arytenoid flap. A similar angle would exist in the case of all animals the plane of the entrance to whose larynx crossed the axis of movement of the descending bolus, the angle being the more marked the more nearly at a right angle this plane crossed this axis, and it is partly to get rid of this angle that the folding forwards of this arytenoid flap takes place. In animals, on the other hand, where the plane and the axis are parallel there is no angle and there is no folding forward of the arytenoid—merely an outwards and inwards movement, an opening and shutting of the lozenge-shaped entrance, as in the case of the Tortoise, Lizard, Frog, Snake, &c. In addition to the above angle, there would be also an inconvenient open angle between the tongue and the epiglottis, in which food particles would be most likely to lodge, and

upon the resilience of the epiglottis, being engaged between it and the tongue, they would give rise to irritation. As a matter of fact, it does sometimes happen that food gets between epiglottis and tongue, but it would surely often happen if the doctrine of the lid-like action of the epiglottis were true.

By my account of the normal closure of the larynx many further points in the anatomy of the larynx and many observations as to its physiology now receive an explanation. Some writers have come near to the truth, and of all Luschka has come nearest, many passages in his writing showing that he has just failed to grasp the whole meaning of what he describes.

The External Thyro-arytenoid Muscle.—The direction of its fibres is in the main from before, backwards and upwards; this is clearly the direction most suited to the folding forwards of the arytenoid cartilage. Thus the origin of the muscle is in front, at the thyroid cartilage as the more fixed end. The insertion of the muscle extends in the vertical direction, well nigh throughout the entire length of the arytenoid cartilage, so that its superior fibres have a great mechanical advantage in inclining the cartilage forwards, while its inferior fibres especially pull it forwards at its base. Owing to its insertion into the outer surface of the arytenoid cartilage, it tends powerfully to rotate the cartilage so inwards that the internal faces of the cartilages come into apposition. Thus the muscle brings about three of the movements of the arytenoid cartilages that close the larynx, viz., rotation inwards, inclination forwards, and gliding forwards at the crico-arytenoid joint. These movements have been seen experimentally upon electrical stimulation in Man.* The fourth movement is the apposition of the arytenoids by the *arytenoideus transversus.*

The muscle thus with the transverse arytenoid forms a sphincter for the larynx.†

Having this function of the muscle in mind, one at once understands why it is such a large muscle, why it extends vertically so far beyond the level of the true cords, and in short why as viewed in a vertical transverse section of the larynx it seems to have so little relation to the true cords: the fact is *it* is (with the transverse arytenoid muscle) *the* true "sphincter vestibuli,"‡ for it rotates inwards the

* Von Ziemssen, 'Die Electricität in der Medizin.'

† The term "constrictor vestibuli" has already been employed, but applied to the ary-epiglottic muscle, by Luschka. This manifestly is incorrect, for this muscle could not constrict the vestibule, *i.e.*, down to the level of the lower border of the superior cords, however much it might constrict the entrance or *aditus laryngis.*

‡ The term "sphincter" is applied by Henle to the aggregate of the thyro-arytenoids, arytenoid and ary-epiglottic muscles, but his notion of the action of this muscular mass is that the arytenoid pulls the arytenoid cartilages together, while the fibres that have in the relaxed condition a bend with the concavity inwards

anterior margins of the arytenoid cartilages, and thus brings together the sides of the vestibule, and then it inclines the arytenoids so as to encroach on the space from above downwards, and from behind forwards—the three muscles, that is, the two thyro-arytenoids and the transverse arytenoid, now grasp the vestibule, so to speak, obliterate its space, and thus close the larynx. With them act the ary-epiglottici so as to close the very entrance.

In certain animals there is no elastic tissue in what would correspond to the true cord (Bland Sutton, 'Journal of Anatomy and Physiology,' "Nature of Ligaments"), which thus is entirely of muscle enclosed in mucous membrane. This seems to indicate the primary importance of the muscle as a muscle rather than as a vibrating cord, a view also expressed by Bland Sutton upon purely anatomical grounds. May it not be simply that the elastic property is secured for the vibrating tissue at a physiologically cheaper rate through fibrous than through muscular tissue?

Nothing is said here of the feeble *thyro-arytænoideus internus*: this, probably, is the proper muscle of the vocal cords, and in any case, from its feeble development and its attachments, it cannot have much influence in closing the larynx.

This description of the mode of closure of the larynx meets the case during both inspiration and expiration. In closure during inspiration the closure is absolute and, after the muscles have once brought the parts into position, is entirely mechanical. This one can easily verify by sucking air down through either the dead or the living larynx. The margins of the aperture come together and remain pressed together by atmospheric pressure. Against expiration the resistance is entirely muscular, for the margins of the aperture open outwards, and air can always be blown upwards so as to force open the closed larynx. The thyro-arytenoid and transverse arytenoid appear to me to be quite adequately developed to resist pressure to a high degree, because, in the first place, these muscles are really not so small as one is accustomed to think they are; and, in the second place, the surface which has to bear pressure in the closed larynx is not extensive.

In such larynges as the Lizard's, the muscle simply rotates the cartilage to close the lozenge-shaped aperture which corresponds to the glottis of Man.

The Arytenoid Muscle.—This muscle must be divided into (1) the two oblique portions, which are really continuations of the ary-epiglottic muscle, and are dealt with under that heading; and (2) the transverse portion. The transverse portion alone is now under consideration. Owing to the articular surface of the arytenoid car-

straighten themselves, and so bring the side walls of the entrance together. This, of course, is quite a different thing from my account.

tilage being on the under surface of the muscular process, which is projected backwards from the cartilage, the surfaces of attachment of the muscle lie in front of the joint, *i.e.*, in front of the fulcrum, so that the muscle powerfully rotates the cartilages inwards, draws them together, apposes their internal surfaces, and pulls them powerfully together. Thus the muscle acts with the thyro-arytenoids as a sphincter of the larynx. The muscle likewise forms an elastic ligament between the two cartilages, fibrous tissues being clearly unsuitable. White fibrous tissues would imply fixity of interval, and elastic tissues would need in certain positions to be stretched by considerable muscular force, while in other positions they would be lax. The muscle likewise forms part of the surface over which the bolus glides in deglutition, but at this time it is in contraction, and therefore firm; and, lastly, it closes in the triangular space which must always remain in front of the lamina of the cricoid, even when the arytenoids are applied to one another by their inner faces.

The Ary-epiglottic Muscle, including the Oblique Portion of the Arytenoid Muscle.—Its function, apparently, is to make tense the ary-epiglottic folds of mucous membrane, part of the immediate boundaries of the entrance. Thus the entrance is bounded during deglutition either by cartilage or by tense muscle, so that the bolus has no chance of entering. The tension is manifest from the more marked backward curvature of the lateral edge of the epiglottis; thus the concavity of the epiglottis becomes more marked, forms, indeed, a deeper groove to receive the tips of the arytenoids during deglutition. On this account the transverse limb of the fissure, or head of the T, is markedly concave backwards.

That the muscle is prolonged over the back of the upper part of the cartilage of its own side to the base of the cartilage of the opposite side is necessary. It thus tends to brace together the two cartilages, whereas, if it only went to the cartilage of its own side, it would tend to separate the cartilages, and thus to destroy the effectiveness of the closure of the orifice.

A subsidiary effect is to help the thyro-arytenoid in rotating inwards and pulling forwards the arytenoids; to this extent therefore, but only to this extent, is the name "constrictor vestibuli" (Luschka) justifiable.

The Lateral Crico-arytenoid Muscle.—Besides rotating the arytenoid cartilage, this muscle must also help in tilting the whole cartilage forwards by pulling the base forwards so that the posterior part of the articular surface comes to rest on the cricoid. Both this muscle and the posterior crico-arytenoid being inserted at the base of the cartilage, therefore very close to the axis of rotation, secure a comparatively large movement with but little actual shortening of the muscles.

In most Mammals the larynx is usually open, and is only shut when some temporary occasion arises. In some Mammals, such as the Porpoise and Dugong (Owen), Grampus, White Whale, Dolphin, &c., the larynx, on the other hand, appears to be usually shut, and here the T-shaped fissure which I have described is quite evident. Is not the usual condition in these Mammals an indication of what is most likely to be the temporary mode of closure in the others?

Birds are extremely instructive in this connexion. Here the vocal function is entirely removed from the larynx, so that the larynx has for its sole office the guarding of the entrance to the trachea. Inspection and experiment show the entrance to be closed by the arytenoid cartilages, or bones, and the thyro-arytenoid muscles. Since this is their function in Birds (and the same applies to Tortoises, Lizards, Reptiles, Frogs, &c.), is it not all the more likely to be at least a function in Mammals? Bland Sutton (*loc. cit.*) in this connexion, and upon other grounds, believes that "the original function of the vocal cord is to protect the air passages, speech being a superadded function." Closure of the larynx is the one never failing office of the larynx, and the arytenoid cartilages and their muscles are the only never failing structures; epiglottis, false cords, true cords, as such, and ventricles may all be absent. Does not this indicate some connexion?

The T-shaped fissure seems to depend upon the presence of an epiglottis; where that is present, it keeps the anterior end of the fissure wide, makes, in short, the transverse head of the T. Where there is no epiglottis and nothing to take its place, the fissure is purely antero-posterior, so that at the vertical limb of the T is the more primitive, and by making a succession of transverse sections of the closed larynx, the head of the T gradually narrows with the narrowing of the epiglottis, so that at the level of the glottis the vertical, *i.e.*, antero-posterior, limb alone remains even in Man. It will be observed that in cutting away the higher parts of the larynx, one has removed that part which is peculiar to Man and other animals having larynges of a similar build. Only the bases of the arytenoid cartilages and the attached true cords remain. This latter level thus corresponds to the opening of, say the Frog or Tortoise, and the shape of the opening is practically the same, a lozenge.

The heightening of the arytenoids in Man appears to give these two advantages: 1st, it permits of the entrance to the air passages having the funnel shape which favours the entrance of air; 2nd, it withdraws the vocal apparatus from the vicinity of the very entrance, so that it is the better protected.

Closure of the entrance to the larynx by "tight closing up of the arytenoid cartilages and ary-epiglottic folds" was observed by the laryngoscope (Bruns, 'Arch. f. Path. Anat.,' vol. 43, 1868, p. 135,

quoted by Luschka) in the case of a girl who had lost the epiglottis by ulceration, but Luschka concludes from a consideration of other cases that this was a mere accommodation gradually effected by the muscles "by prolonged practice acquiring the necessary strength to mutually approximate the side walls" of the vestibule. In the case reported by myself with McCormick already referred to, the patient, *immediately* upon the cessation of feeding by the stomach-tube, could swallow as well as he did later on, and to all intents and purposes as well as he could before the operation, and in him we were able to see by merely looking through the hole in the side of the neck, that the laryngeal closure was accompanied by the T-shaped fissure. Here, therefore, there was no "prolonged practice"; there was no practice at all, and the same remark applies to the cases already quoted as having been examined for me by Barrett. The fissure is also shown in Czermak's classical work, but the formation of the head of the T is misinterpreted; it is said to be by the backward movement of the epiglottis, instead of by the forward movement of the arytenoids.

Short of complete closure, the arytenoid flap comes forward so that it is approximated to the front wall of the laryngeal cavity, therefore, in Man, to the epiglottis, and if air be now expired, the characteristic sound of straining is produced by the vibration of the margins of the entrance to the air passages, not of the vocal cords merely.

Lister (Holmes 'Surgery,' Article on "Anæsthetics") ascertained laryngoscopically that true chloroform stertor is produced by vibration "of the posterior part of the arytæno-epiglottidean folds, which are carried forwards to touch the base of the epiglottis during the stertorous breathing, and are placed in still further apposition with it when the obstruction becomes complete." Thus, Lister saw "an antero-posterior co-aptation of the structures of the laryngeal aperture at a somewhat deeper level; without any change in the position or form of the epiglottis, towards which the folds of the mucous membrane above the apices of the arytenoid cartilages are carried forwards till they are in contact with its base. This is seen in coughing and also in laryngeal stertor." Nevertheless, the closure by the epiglottis is the mode of closure Lister adopted for deglutition.

In certain lesions of the true cords, the gruff voice is, as Sir Joseph Lister communicated to me orally, to be ascribed to a vibration of the ary-epiglottic folds, a suggestion with which I entirely agree. I believe also that in gargling, the larynx is almost closed, and the air issues under pressure from the narrow fissure I have described.

In the Kangaroo apparently a great extent of the arytenoids is exposed to the friction of the passing bolus, and along the ridge of the apposed arytenoids, where the friction takes place, the cartilage shows through, and the mucosa is not movable. In the human larynx this

arytenoid ridge contains the antero-posterior limb of the T-fissure, but it is much shorter and less prominent than in the Kangaroo.

The elastic nature of the tips of the arytenoids and the Santorinian cartilages admirably fits them for gliding into position down the front of the laryngeal cavity. In this respect also, the form of the Santorinian cartilages, convex forwards in the closed aperture, helps, and the cushion of the epiglottis, when present, corresponds to the interval between them. In the open aperture, the tips of the cornicula are directed inwards and backwards, but this merely brings them parallel when the arytenoids are in the closed position. The elastic nature of all these cartilages enables them to fit each other perfectly when brought into apposition, and to recover their shape when the pressure is removed, and the pad of fat in front of the epiglottis helps in this connexion. Even in the dead subject, these phenomena can be observed more or less by simply pressing the arytenoids forwards—the closure is perfect without the epiglottis ever moving.

In animals with the cornicula more highly developed than they are in Man and the Goat, this account does not apply. In the Dog, for instance, they are long and pointed, and are pushed aside out of the mesial plane when the larynx is closed.

The superior or false vocal cords, as the arytenoids are rotated inwards, of course, come into apposition with each other, since posteriorly they are attached to the anterior margins of the arytenoids and anteriorly they are attached together to the re-entrant angle of the thyroid cartilage. As the arytenoid cartilages move forwards, the superior cords are shortened from before backwards, and possibly this may account for the large amount of elastic tissue in their structure, and it may possibly be the office of the bundles of striped muscular fibres, which have been described as radiating into the false cords from various muscles of the region, to perform a similar function, that of taking up the slack of the shortened false cord. As the action of the thyro-arytenoid is continued, the soft substance of these cords will tend to be squeezed both upwards into contact with the advancing arytenoids, and downwards to encroach on the ventricle. At the same time, the sacculi will be compressed from the sides by the thyro-arytenoids and from behind by the arytenoid cartilages. This may be the reason why the sacculus is over only the anterior part of the ventricle, for here it is out of the way of the advancing arytenoid, and any secretion which might be squeezed out of it would immediately pervade the whole length of the ventricle, now narrowed by the encroachment of the false cords, and so would lubricate the whole length of the true cord, although the sacculus is over the anterior part only. The fact that we often swallow when the cords are dry, as in hoarseness after much speaking, supports this idea, for the saliva swallowed cannot possibly affect the cords; the

act of swallowing, however, could, by expressing the saccular secretion, and distributing this secretion as well as the copious secretion of the rest of this region over the true cords.

The Crico-arytenoid Joint.—The relatively great antero-posterior diameter, the ovoid form, and plane surface of the arytenoid articular surface, in the light of this description of the mode of closure of the glottis are quite comprehensible.

As the vocal process of the arytenoid with its attached true vocal cord sinks into the larynx, it moves nearly in a circle, of which the cord is the radius, and the cartilage glides forwards on the cricoid, so that the cord's tension remains fairly equable. As a matter of fact, however, the tension of the cord in the sunk position is greater than before, so that the mere gliding of the arytenoid does not wholly compensate: the tilting forward of the whole cartilage is relatively great, so that the vocal process is carried relatively far backwards and so the cord is put upon the stretch.

When the larynx is open the narrow end of the ovoid rests on the cricoid, but in the closed larynx it is the broad end of the ovoid. In the open larynx, stability is not of moment; rather is mobility important, for there is no pressure to be resisted and in swallowing it is of importance to get the cartilages quickly into position, and, moreover, we saw that the arytenoids are in continual movement even in tranquil respiration. In the closed larynx, on the other hand, stability is of the utmost moment, and then, not only is the broad end of the ovoid on the cricoid, but possibly the little intra-articular fibro-cartilage attached to the capsular ligament of the articulation, and projecting into the joint cavity from the posterior blunt circumference of the arytenoid articular surface (Luschka), comes into play to increase the surface upon which the arytenoid rests: only along a line can there be contact of the cricoid cylinder with the arytenoid plane, but the fibro-cartilage probably increases this surface of contact so that the arytenoid rests on the cricoid in front, and on the intra-articular cartilage behind. The fibro-cartilage filling up the angle of the joint posteriorly would play also the part of a sort of patella protecting this extremely important joint from any mechanical violence from the passing bolus.

A further advantage of the gliding forwards of the arytenoid is that, while in the open larynx the muscular process projects somewhat behind the plane of the cricoid lamina, in the closed larynx it does not, so that there is no impediment to the descending bolus, and less chance of damage to the cartilage and joint.

The long axis of the arytenoid articular surface is from behind inwards and forwards, and this is the direction in which the base glides.

The arytenoid cartilages of course glide laterally also, for the

cricoid articular surface is about half as long again as the arytenoid is broad—in the open larynx the arytenoids rest on the outer end of the cricoid surface, in the closed larynx on the inner end, so that they now lie closely apposed. Thus the action of the three true sphincter or constrictor muscles brings the arytenoids exactly into the position described in the closed larynx; the *thyro-arytenoidei* rotate the arytenoid cartilages inwards and pull them forwards, the *arytenoideus transversus* pulls them together. The narrowing of the lamina of the cricoid as we ascend has an important influence in permitting the arytenoids to approach each other bodily, though a triangular space, the base of which corresponds to the width of the cricoid lamina, must always remain filled by the *arytenoideus*.

The epithelium on the inner faces of the arytenoid cartilages is stratified squamous (Davis, quoted by Klein), and this is accounted for by the pressure between the two comparatively hard and resistant arytenoids. Covering the greater part of the side walls of the vestibule it is ciliated columnar, but there being no rubbing of surface upon surface, the mucosa being soft, and the surface being covered by a thick layer of mucus, the cilia are not damaged by the compression of the vestibule in deglutition. The epithelium for a little way within the margin is stratified squamous; here, however, one can imagine that some friction takes place during the movements of the parts.

The shape of the epiglottis fits in with my account of the act of deglutition: it lies on the posterior part of the dorsum of the tongue, but it would certainly not fit the top of the larynx did it fold over it as in the current description, for there is no relation either in size or form, nor is there any pattern on its laryngeal surface as if it were often applied to the laryngeal aperture. And, as Howes writes ('Jl. Anat. Physiol.,' 1889, p. 271), "In many Quadrupedal Mammals the parts are so arranged that the posterior border of the velum appears to overlie the epiglottis, abutting against the ventral laryngeal wall. In such a case, did the epiglottis merely function, during deglutition, as a lid, the effects of its displacement would be simply that of forcing it back upon the velum palati. A flapping action in deglutition, as ordinarily understood, could manifestly only be possible in forms in which the velum stops short of the epiglottis."